Energy and Buildings 43 (2011) 3208–3215

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Thermal and economic windows design for different climate zones

Samar Jaber*, Salman Ajib

Technical University of Ilmenau, Department of Thermodynamics and Fluid Mechanics, P.O Box 100565, 98648 Ilmenau, Germany

ARTICLE INFO

Article history:
Received 8 May 2011
Received in revised form 12 August 2011
Accepted 16 August 2011

Keywords:
U-value
Optimized
Life cycle cost (LCC)
Glazed
Energy

ABSTRACT

Window design, especially glazing choices, is a critical factor for determining the effectiveness of passive solar design. Windows are like a knife has two side; one is useful and the other is harmful. In this paper the effects of windows' *U*-value, window orientation and windows size on annual heating and cooling energy demand is studied considering the both energy and investment costs. The study has been performed for three different climate zones; Amman, Aqaba and Berlin. Four types of windows have been studied; single glazed, double glazed L, double glazed H and triple glazed.

The results show that heating load is highly sensitive to windows size and type as compared with cooling load. Also, it is shown that with a well-optimized glazed window energy saving can be reached up to 21%, 20% and 24% for Amman, Aqaba and Berlin, respectively.

1. Introduction

Buildings are constructed to accommodate human activities so that they have to be conducted in thermal and visual comfort [1]. The goal of meeting the user's need for a comfortable environment involves achieving and maintaining acceptable levels of interior comfort, day and night, all year around [2]. On the other hand, windows are important for both psychological and environmental reasons. Good glazing design can reduce energy outputs by lowering heating or cooling requirements. Windows are also important for the provision of daylight and a view, both of which have known psychological benefits [3].

Sullivan and Selkowitz [4] have analyzed single, double and triple glazed windows in terms of their energy efficiency for hot and humid, hot and dry, temperate and cold climates of USA [4].

As mentioned by Rousseau [5], double-glazed or triple-glazed windows, in which there are two or three panes of glass sandwiched together with a layer of air or inert gas between each pane, have more thermal resistance than single pane windows. This is because the layer of air between the panes impedes the flow of heat, while the glass itself does almost nothing to prevent the heat flow exchange [5].

Gertis [6] examined the subject of double façade systems very critically. Considering all of the physical influences (acoustic, fluid and thermal characteristics, energy, light penetration and fire protection), he concluded that double-glazed façades – except for special cases – are unsuitable for the north European climate and too expensive [6].

A dynamic building simulation tool, DEROB-LTH, was used to simulate energy demand for the houses with modern coated triple-glazed windows. The results show that the size of the energy efficient windows does not have a major influence on the heating demand in the winter, but is relevant for the cooling need in the summer [7]. This indicates that it is possible to decrease the risk of excessive temperatures or energy needed for cooling, there is an optimal window size facing south that is smaller than the original size of the investigated buildings.

It is shown that it is possible to calculate the yearly energy demand for heating, cooling and electric lighting as a function of window position, window size and window shape for an office environment in the Netherlands by Bokel [8]. An optimal window size for this office simulation was around 30% of the façade area, where the window is positioned in the top half of the façade. This would lead to an overall energy load of 1400 kWh per year. A window size of 20–40% is also very acceptable. For larger window sizes, starting at 50%, the advantage of a larger glass area on the lighting load is negligible. As a larger window area increases the cooling load significantly, the net primary energy load increases for larger window sizes [8].

Thermal load and energy performance involves understanding complex heat transfer relationships between building parameters and external parameters. External cooling loads of a building façade are caused mainly by shortwave irradiance transmission [9]

It is seen that the annual energy saving by a particular window depends upon several factors: window's own two parameters (*U*-value and *g*-value), its orientation, climatic conditions and building parameters [10].

* Corresponding author. Tel.:+49 17675233854.
E-mail addresses: samar.Jaber@tu-ilmenau.de, s0jaber@gmail.com (S. Jaber), salman.ajib@tu-ilmenau.de (S. Ajib).

0378-7788/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2011.08.019

The influence of windows on heating demand of apartment buildings in Amman is investigated by Hassouneh et. al. The results show that if energy efficient windows are used, the flexibility of choosing the glazed area and orientation increases [11]. This work investigated the performance of single, double and triple glazed window for both heating and cooling demand in three different climate zones.

Although about one-third of the total heat loss of buildings occurs through windows which makes undesirable from an energy conversation point of view, there are few studies published about the optimization of glazing in buildings [12]. Although there are a great number of studies about the optimum thickness of walls insulation material, there are few studies published about the optimization of glazing in buildings. Thus, in this study the optimum windows type and size considering both energy (heating and cooling energy) and investment costs is simulated for three climate zones (Amman, Aqaba and Berlin). These provide a simple means to designer to select best energy performing window and size for a given climate conditions.

2. Thermal model

The building model in this study can be described as follows:

- The floor area is about 154 m^2, perimeter is 43.4 m and ceiling height is 3 m. It consists of three bedrooms, living room, guest room, Kitchen and three bathrooms.
- Number of occupants is 6 persons.
- The building is a rectangular shape with overall heat transfer coefficient (U) of 0.133 W/(m^2 °C) and 0.149 W/(m^2 °C) for wall and ceiling, respectively.
- The climatic outdoor design data (solar radiation, ambient temperature, relative humidity, ...) is hourly data obtained from INSEL library [13].
- The minimum windows size is 10% from the façade area as mentioned in IBC Code [14] and Energy Efficient Building Code [15] in order to reach human comfort.
- Thermostat setting is adjusted at 24 °C and 20 °C for cooling and heating, respectively where the relative humidity is set 50% for cooling and 30% for heating [16].
- All windows are glass with aluminum frame (U = 2.27 W/(m^2 °C)) which considered as one of the popular windows type.
- This building is ventilated according to ASHRAE Standard 62.2 [17].

The demand for both heating and cooling is strongly influenced by the outdoor air temperature, T in degree celsius and global solar radiation on horizontal plate around the building, G_h in (kWh/m^2). These data is listed in Table 1; for selected locations [13].

Aqaba city is characterized by very hot and dusty weather in summer; summer temperatures rise above 46 °C [13]. Winter is mild therefore there is little need for heating with extremely little amount of precipitation. The mean annual daily average temperature is estimated at around 24.1 °C [13].

In Amman, summer starts around mid of May and winter starts around mid of November, with two short transitional periods in between (autumn and spring). In summer, high temperatures reach above 35 °C on most days in June, July and August [13]. Nights are comfortable with average low temperatures of 14.4 °C in June, 14.7 °C in July and 14.8 °C in August [13]. Amman gets absolutely no rainfall during an average summer. Winter is Amman's wettest season. The coldest month in winter is January. Frosty mornings are common in Amman and snow falls once or twice during the season.

The city of Berlin stands on the eastern side of Germany and enjoys characterized by mild summer weather. The maximum temperature in summer is 30.3 °C in August [13]. Berlin is also characterized by its cold winters. December, January and February are the coldest during the year. The lowest temperature in winter is −11.5 °C in December [13]. The annual daily average temperatures in Berlin is around 8.8 °C [13].

Table 1
Daily average weather data for different location.

Month	Amman		Aqaba		Berlin	
	T_{db} °C	G_h kWh/m^2	T_{db} °C	G_h kWh/m^2	T_{db} °C	G_h kWh/m^2
Jan.	6.5	2.9	15.5	3.5	-2.3	0.6
Feb.	7.5	3.5	17.0	4.0	0.6	1.0
Mar.	12.3	4.7	21.0	5.1	4.0	2.5
Apr.	15.0	5.7	22.3	5.7	7.9	3.5
May	19.7	6.9	27.8	6.8	14.4	4.9
June	23.4	7.6	30.1	7.4	15.8	5.4
July	24.6	7.7	31.8	7.5	17.1	5.4
Aug.	24.3	7.2	30.4	7.1	19.0	4.8
Sep.	23.2	5.8	28.5	6.0	14.5	3.1
Oct.	20.6	4.8	26.0	5.1	10.2	1.7
Nov.	15.4	3.4	22.7	3.8	4.9	0.8
Dec.	9.1	2.8	15.7	3.2	-0.1	0.5
Average	16.8	5.2	24.1	5.4	8.8	2.8

Window's performance in terms of energy efficiency can be assessed mainly by looking at its U-value and solar heat gain coefficient (SHGC). U-value indicates the rate of heat flow due to conduction, convection, and radiation through a window as a result of a temperature difference between the inside and outside. The higher U-value the more heat is transferred. SHGC indicates how much of the sun's energy striking the window is transmitted through the window as heat. As the SHGC increases, the solar gain potential through a given window increases.

The glass temperature is varied every time step according to solar heat. The temperature accordingly is calculated every hour at corresponding solar heat. Then the heat convection is calculated by taken the difference temperature between glass temperature and indoor temperature. Window's load consists of the following components [18]:

- Load due to convection which is calculated every hour by the following equation:

$$Q_{conv.} = U * A * \Delta T * \Delta t \tag{1}$$

where U is the overall coefficient of heat transfer (kWh/(m^2 °C)), A is the window area (m^2), ΔT is the total equivalent temperature difference, which takes into consideration the increase of wall temperature due to absorbtion of solar radiation (°C) and Δt is the length of the time step in hour.

- Load due to solar transmission and radiation. This is calculated from the following equation:

$$Q_{tr.} = \mathrm{SC} * \mathrm{SHGC} * \mathrm{CLF} * A * \Delta t \tag{2}$$

where SC is the shading coefficient, SHGC is solar heat gain factor (kW/m^2) and CLF is the cooling load factor.

Four windows' types will be investigated in this study as well as windows size by using TRNSYS software [19]. The size of windows at each façade is varies between 10% and 90% from the total façade area. Windows thermal characteristics are presented in Table 2. where Rf-sol is solar reflectance of outer surface of glazing system and T-vis is visible transmittance of the window.

Table 2
Thermal characteristics of windows.

	Singleglazed	Double glazed L	Double glazed H	Triple glazed
U	5.68	2.83	1.4	0.68
SHCG	0.855	0.775	0.589	0.407
Rf-sol	0.075	0.126	0.266	0.231
T-vis	0.901	0.817	0.706	0.625
Gas fill	–	Air	Argon	Krypton

3. Economic model

In order to perform economic analysis, it is necessary to obtain windows initial cost. Then, an optimization window type and size is estimated using economic figures from local markets for each location using life cycle cost (LCC) criterion. The estimation costs of this system in addition to conventional energy systems do involve some basic assumption which can be summarized as follows:

- The life span of the building and auxiliary heating system is assumed to have 30 years. The auxiliary cooling used in this work is assumed to have 10 years.
- According to Jordanian market the inflation rate is around 8.9% and the interest rate is about 6.25% as mentioned by Central Bank of Jordan (CBJ). Thus, present worth factor, PWF, which is a function of interest rate, r, and inflation rate, i, can be calculated from Eq. (3). PWF is equal to 44.96 and 11.48 at 30 and 10 years, respectively.
- According to German market the inflation rate is around 1.90% and the interest rate is about 1.00% as mentioned by Deutsche Bundesbank. Thus, present worth factor, PWF, which is a function of interest rate, r, and inflation rate, i, can be calculated from Eq. (3). PWF is equal to 34.52 and 10.50 at 30 and 10 years, respectively.
- The auxiliary heating system has an efficiency of 65%.
- The auxiliary cooling system has coefficient of performance (COP) of 3.
- The salvage factor, f_{salv}, is set at 10% of the capital cost for the auxiliary heating and cooling systems.
- Maintenance factor for the auxiliary heating and cooling systems, f_m, is assumed to be 15% of the capital cost.
- Current fuel price is 0.455 Euro/l where the electricity price is 0.085 Euro/kWh in Jordan [20].
- Current fuel price is 0.653 Euro/l (http://www.tecson.de) where the electricity price is 0.250 Euro/kWh in Germany (www.verivox.de).

The objective function which will be optimized is LCC function which equal to [21];

LCC = (auxiliary system cost + maintenance cost for auxiliary system − auxiliary system salvage cost) + (basic material cost + windows cost) + (annual auxiliary energy cost − annual cost of saved energy due to windows) or;

$$\begin{aligned} \text{LCC} \; = & \; C_{aux,heat}(A_w)\left[1+f_m\text{PWF}-f_{salv}\left(\frac{1+i}{1+r}\right)^N\right]_{aux,heat} \\ & +C_{aux,cool}(A_w)\left[1+f_m\text{PWF}-f_{salv}\left(\frac{1+i}{1+r}\right)^N\right]_{aux,cool}+C_{B.M} \\ & +C_w(A_w)+\left[(Q_{aux,heat}-Q_w(A_w))\frac{p_d}{\eta aux,\,heat}PWF\right]_{aux,heat} \\ & +\left[Q_{aux,cool}-Q_w(A_w)\frac{p_e}{\text{COP}}\text{PWF}\right]_{aux,cool} \end{aligned} \tag{3}$$

where A_w: percentage of windows area from total façade area; $C_{B.M}$: cost of building basic material (stone, concrete, glaze, etc.); C_w: windows cost; $C_{aux.,heat}$: auxiliary heating system cost; $C_{aux.,cool}$: auxiliary cooling system cost; $Q_{aux.,heat}$: annual auxiliary heating energy consumption (base load); $Q_{aux.,cool}$: annual auxiliary cooling energy consumption (base load); Q_w: annual saved energy due to windows; f_m: maintenance fraction; PWF: present worth factor.

$$\text{PWF} \; = \sum_{j=1}^{N}\left(\frac{1+i}{1+r}\right)^j = \frac{1+i}{1+r}\left(1-\left(\frac{1+i}{1+r}\right)^N\right) \tag{4}$$

f_{salv}: salvage fraction; i: inflation rate; r: interest rate (equivalent to discount rate); N: period of investment; p_d: thermal energy price; p_e: electrical energy price; $\eta_{aux.,heat}$: auxiliary heating system efficiency; COP: auxiliary cooling system coefficient of performance.

Finally, the payback for the cost of window can be calculated by dividing the cost of window over the amount of money which can be saved each year by utilizing the solar energy and reducing thermal losses. Therefore, the payback period can be written as:

$$\text{Payback period (PbP)} = \frac{\text{window cost}}{\text{energy saving cost}} \tag{5}$$

4. Results

4.1. Thermal optimization

The effect of glazing in three climate zones is simulated by using TRNSYS software. Four different types of windows are selected; single, double-Low, double-High and triple glazed. The Annual heating energy versus windows area for different window types is presented in Figs. 1–3 for Amman, Aqaba and Berlin.

It is obvious from these figures that the effect of decreasing windows' U-value is decreasing the annual heating energy in Amman, Aqaba and Berlin climate zones. Moreover, the highest annual heating energy is occurred at North façade for all locations due to low solar incident radiation at this façade. The lowest annual heating energy occurred at South façade in Amman, Aqaba and Berlin. This is due to high solar incident radiation at this façade as compared with other façades.

For single glazed windows, the annual heating energy is linearly increased as windows area increased in all regions. That's mean this type of windows is not sufficient energetically to be installed for heating purpose. This is due to high windows U-value. Fig. 2 shows that the effect of single glazed windows in Aqaba climate at West, East and South façades is almost the same.

For double glazed-Low windows, the annual heating energy for all regions at North façade is always increased as windows area increased. The heating load for South, East and West façades is decreased at the beginning then it is increased as windows size increased in both Amman and Aqaba climate zones, as shown in Figs. 1 and 2. In Berlin, the annual heating energy is linearly increased as windows area increased, as plotted in Fig. 3. The optimum windows area in Amman is 40% for both South and East façades, 10% for North façade and 20% for West façade. The optimum size in Aqaba is 20% for both West and East façades, 10% for North façade and 30% for South façade. In Berlin, double glazed-Low doesn't show any sufficient decreasing in annual heating energy. This is due to very low ambient temperature in winter.

For double glazed-High windows, the annual heating energy in Amman, Aqaba and Berlin tends to decrease at the beginning then it's increased except at North façade which is linearly increased as windows area is increased. The optimum windows area in Amman, as shown in Fig. 1, is 70% for both South and West façades where it is 10% and 80% for North and East façades, respectively. The thermal heat losses through windows become more than solar gain after these optimum percentages. This is happened when ambient temperature is lower than room temperature during winter time that leads to increase the thermal heat losses. In Aqaba, the optimum windows area is 80% for South and West façades where it is 90% for

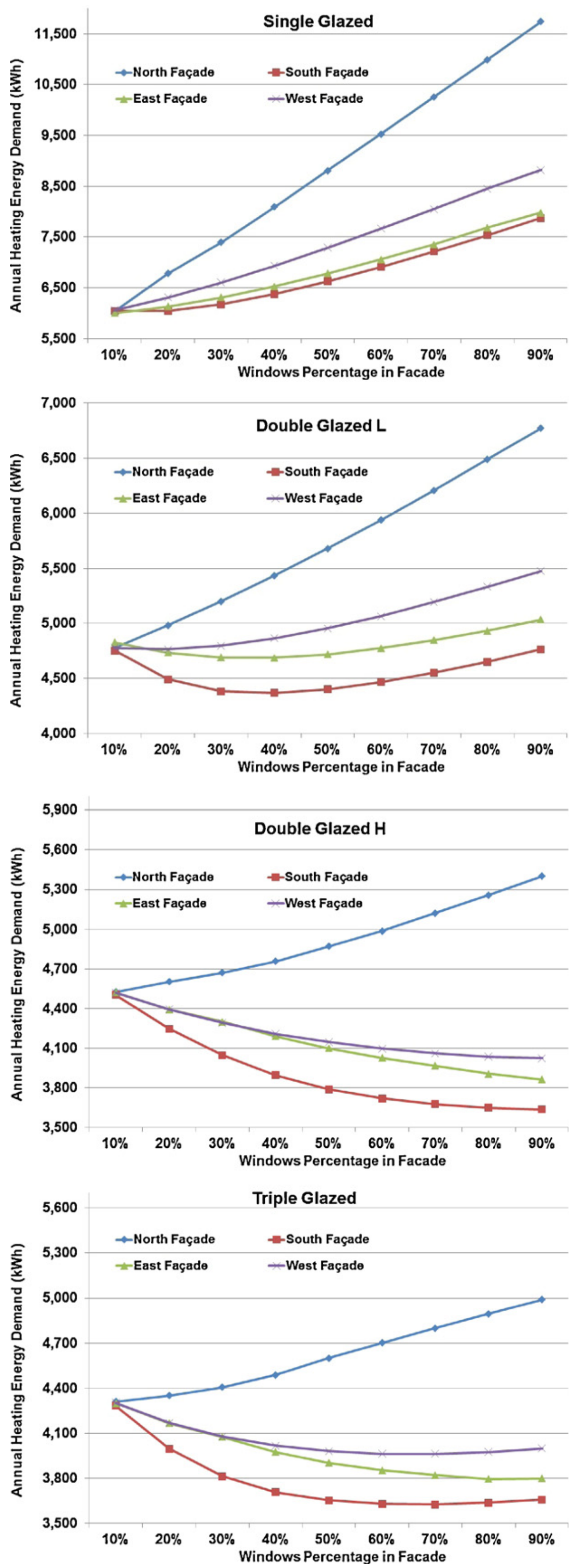

Fig. 1. Effect of windows' type and size on heating load in Amman.

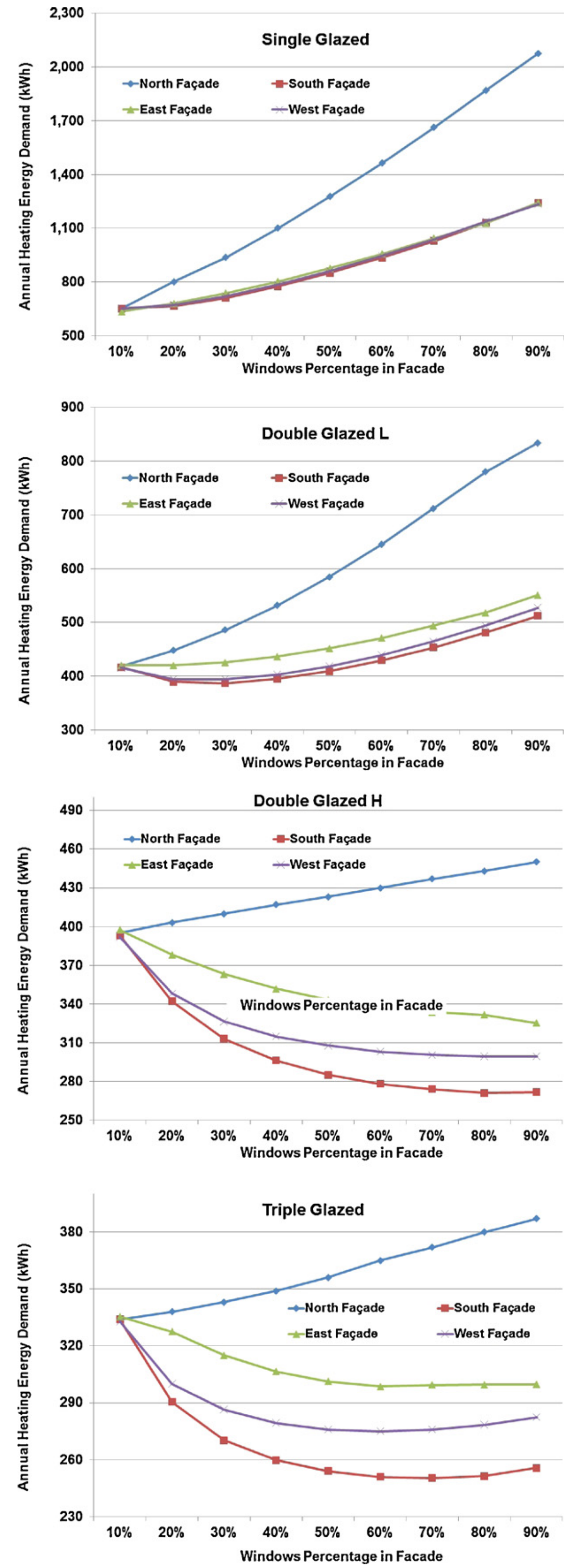

Fig. 2. Effect of windows' type and size on heating load in Aqaba.

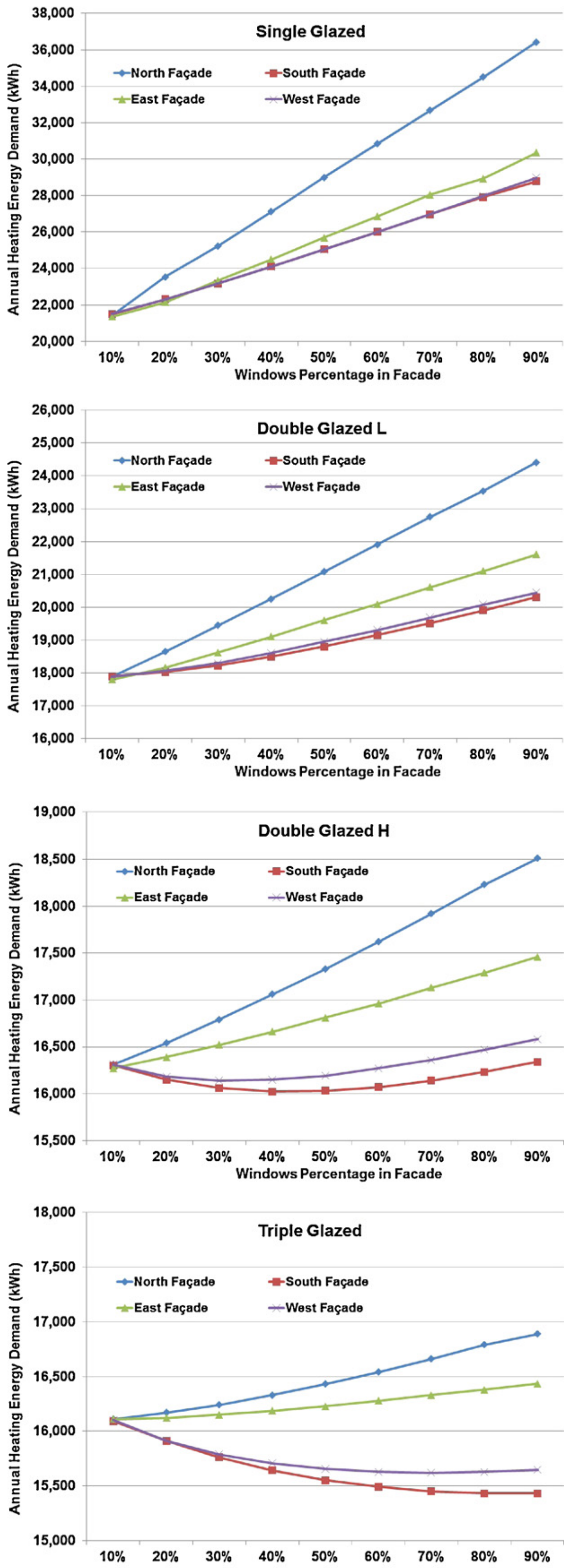

Fig. 3. Effect of windows' type and size on heating load in Berlin.

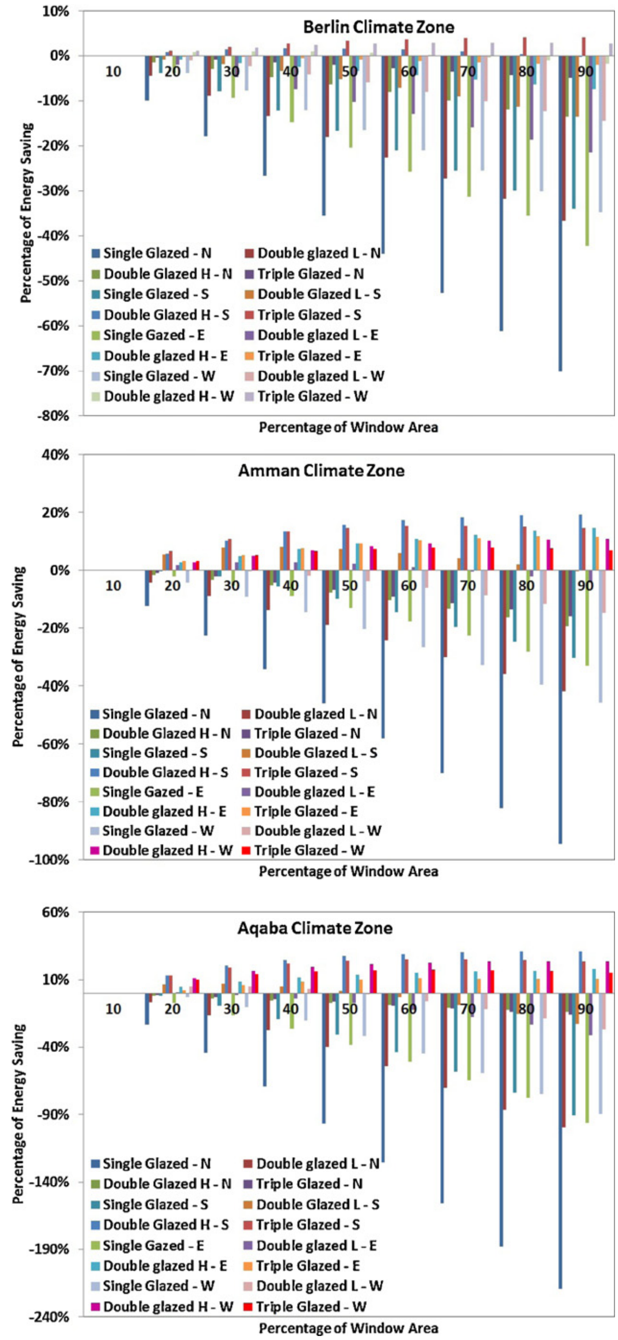

Fig. 4. Energy saving or losses as a function of windows' area.

East façade and 10% for North façade, as shown in Fig. 2. For Berlin climate zone, Fig. 3 shows that optimum windows area is 10% for East and North façades and it is 40% and 30% for South and West façades, respectively.

In case of using triple glazed windows, heating load tends to decrease as windows area is increased in all climate zones, till reaching the optimum windows' size, then it is increased except at North façade. It is shown from Fig. 1 that the optimum windows' size in Amman is 10%, 90%, 90% and 90% for North, South, East and West façades, respectively. The optimum windows' size in Aqaba is occurred at 70% for both South and West façades and at 10% and 60% for North and East façades, respectively as shown in Fig. 2. In Berlin climate zone the optimum can be achieved, as shown in Fig. 3, at 10% for both North and East façades and at 70% and 80% for West and South façades, respectively.

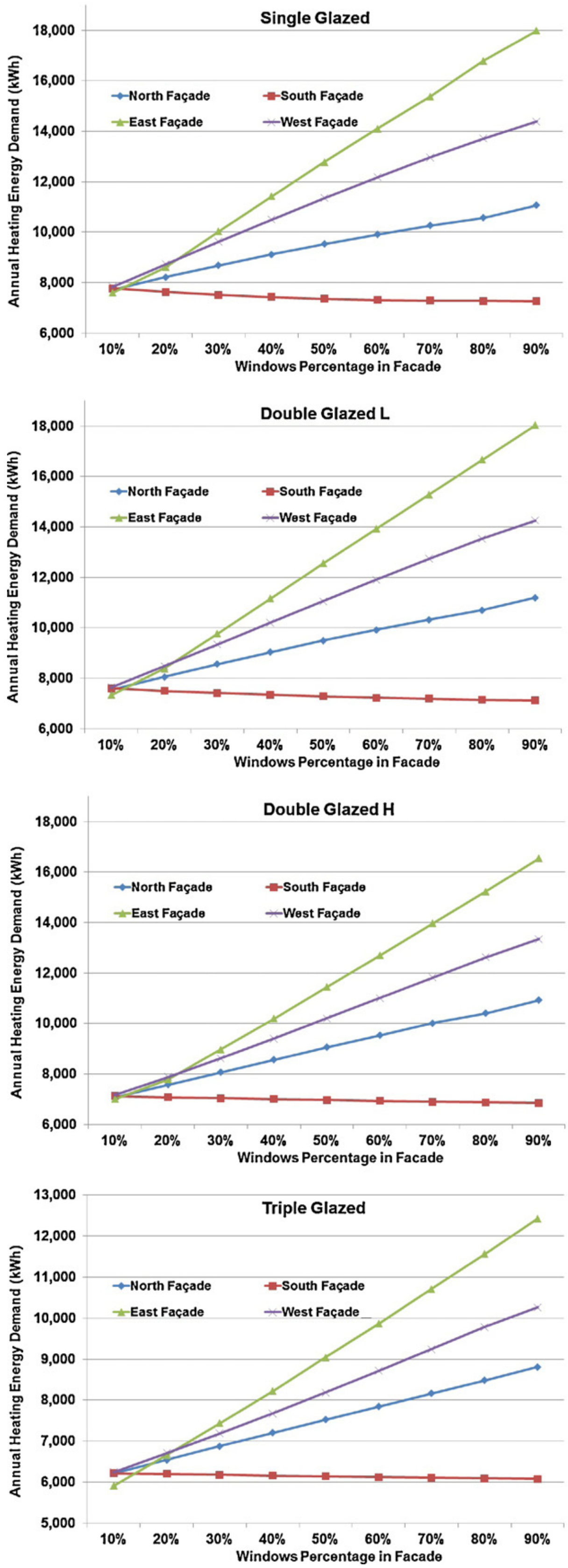

Fig. 5. Effect of windows' type and size on cooling load in Amman.

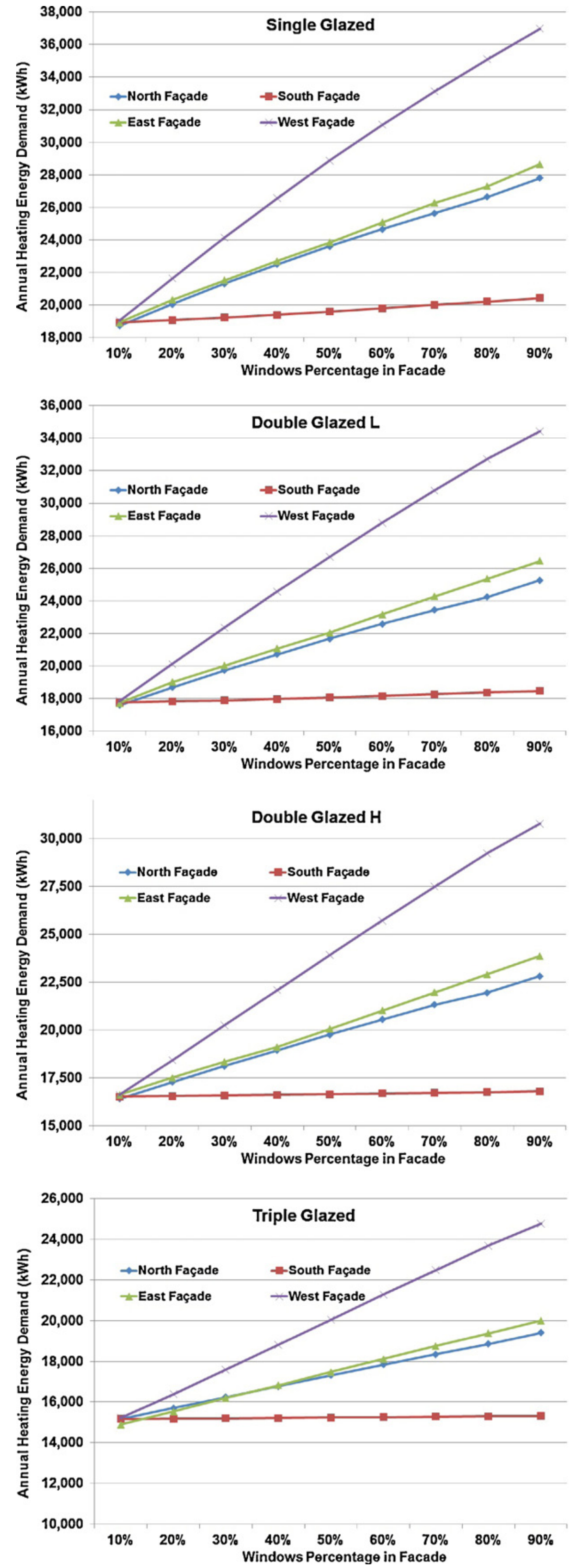

Fig. 6. Effect of windows' type and size on cooling load in Aqaba.

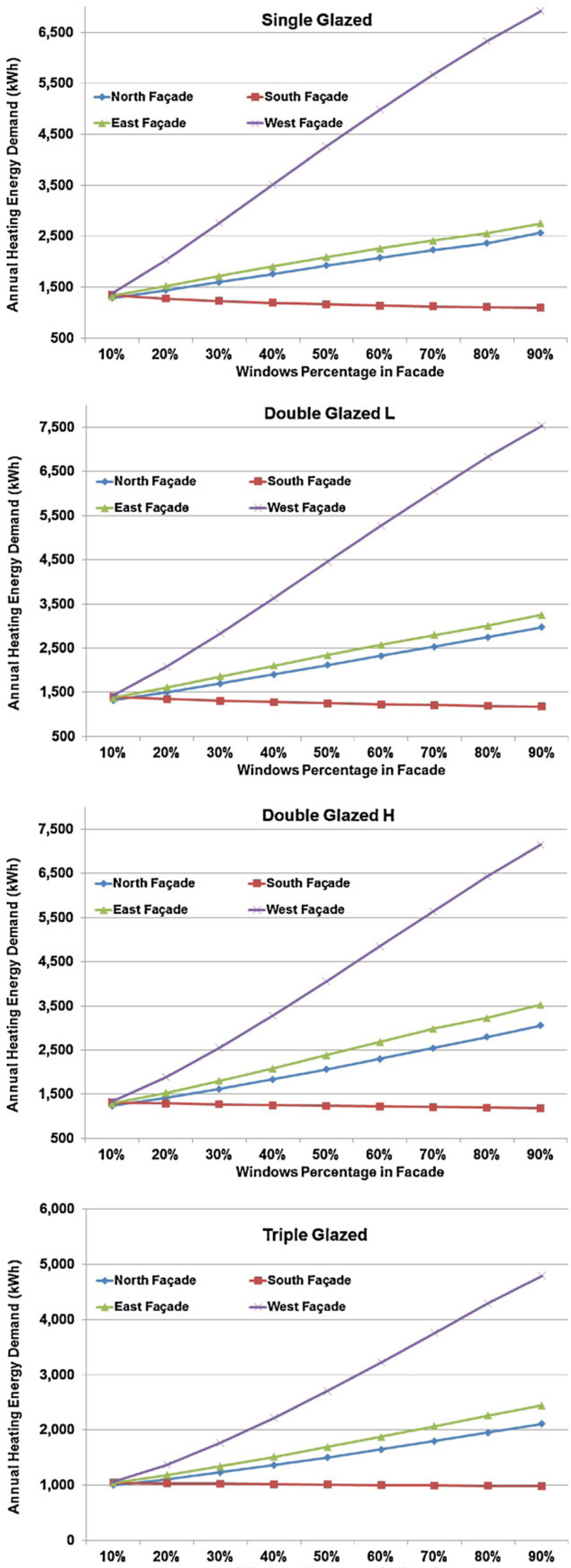

Fig. 7. Effect of windows' type and size on cooling load in Berlin.

The percentage of energy saving or losses as function of windows' area ranges from 0% to 90% is presented in Fig. 4. The highest saving amount is occurred at South façade where the highest losses is occurred at North façade. For all climate zones, increasing windows' area at North façade will cause more energy losses. Therefore, it is recommended to set windows' area at North façade to minimum size. This will reduce heat losses from the heated space.

Once windows' area at South façade is increased the opportunity of saving energy is increased till optimum value is reached except for single glazed window in all climate zones and for double glazed-Low windows in Berlin, as shown in Fig. 4. In these cases, the losses increase as windows' area increase due to high windows' U-value.

For East and West façades, good opportunity of energy saving can be achieved in triple and double glazed-High in all climate zones except double glazed-High in Berlin. On the other hand, the energy saving at West façade is slightly higher than East façade in Aqaba and Berlin. In Amman, East façade is achieved higher energy. This is due to high temperature after mid-day than before mid-day which is the opposite in Amman region.

The annual cooling energy versus windows' area for different windows' types is presented in Figs. 5–7 for Amman, Aqaba and Berlin. These results show that the annual cooling energy is slightly decreased as windows' U-value decreased for all locations. This occurs because windows with low U-value conduct less energy from outside to inside building during hot summer months. On the other hand, it is avoid the heat conduction from outside to inside building when ambient temperature is less than room temperature during summer night.

The annual cooling energy is increased linearly as windows' area increased. This is due to the negative effect of solar radiation in summer. That's mean the better solution to avoid high cooling energy is blocking the windows. On the other hand, windows are decreased the heating energy in winter and it should be existing to avoid artificial lighting and provide occupants with minimum level of comfort according to building codes and standards. Thus, in order to take best decision all above factors have to be taken into consideration as well as windows' cost.

Concerning summer performance, the main argument against lower windows' U-value is the overheating and unwanted gains to the room. It is concluded form the simulation results that the peak energy demand is increased as windows U-value decreased. Thus, shading device has to be used at South façade to achieve summer comfort.

Figs. 7 and 6 show that in Berlin and Aqaba, the cooling energy at West façade is more than at East façade. This is because of the ambient temperature and the solar radiation after mid-day is more than before mid-day.

4.2. Economic optimization

Optimum windows' size at different windows' type are calculated by using LCC in three climate zones. The results are presented in Table 3.

Table 3 shows that double glazed-Low windows are cost effective in both Amman and Aqaba. Windows' size of 10% at North façade, 30% at South façade, 20% at East façade and 10% at West façade achieve the minimum LCC in Amman. The payback period of extra investment from annual saving is about 14 years. The optimum windows' size in Aqaba region are 10% at North façade, 10% at South façade, 10% at East façade and 10% at West façade. The payback period is a little bit high which equal to 21 years.

In fact, double glazed-High and triple glazed windows are not existing in Jordanian market. The window price is estimated according to German market plus transportation costs. In future if these products are locally manufactured or exported in large amount the initial cost will be reduced by 40% which will directly

Table 3
Economic analysis for different windows' types for Amman, Aqaba and Berlin.

	Energy demand (kWh)	LCC (Euro)	Energy saving (%)	PbP (Year)
Amman (N,S,E,W)				
Single glazed (10%,10%,10%,10%)	13,290	81,475	–	
Double glazed L (10%,30%,20%,10%)	12,567	77,412	5	14
Double glazed H (10%,10%,10%,10%)	11,009	81,982	17	70
Triple glazed (10%,10%,10%,10%)	10,488	86,614	21	109
Aqaba (N,S,E,W)				
Single glazed (10%,10%,10%,10%)	19,215	85,072	–	
Double glazed L (10%,10%,10%,10%)	17,886	81,842	7	21
Double glazed H (10%,10%,10%,10%)	17,119	83,531	11	80
Triple glazed (10%,10%,10%,10%)	15,327	89,476	20	128
Berlin (N,S,E,W)				
Single glazed (10%,10%,10%,10%)	22,405	131,473	–	
Double glazed L (10%,10%,10%,10%)	19,052	119,121	15	3
Double glazed H (10%,10%,10%,10%)	17,540	116,877	22	11
Triple glazed (10%,10%,10%,10%)	17,083	119,473	24	15

affect on its economic feasibility through the whole life of the building.

For Berlin climate zone, double glazed-High windows of 10% at North façade, 10% at South façade, 10% at East façade and 10% at West façade is the optimum case, as shown in Table 3. The payback period is considered as reasonable value which is 11 years.

The lower payback period in Berlin as compared with Amman and Aqaba is due to lower interest and inflation rate in Berlin in addition to higher energy saving achieved.

5. Conclusions

To authors knowledge, this is the first comprehensive simulation analysis of the influence of windows type and area in three different climate zones (Amman, Aqaba and Berlin) taking into consideration both summer and winter seasons. Moreover, LCC has been investigated to find the clever choice of glazing in order to save energy.

The main findings of this study are outlined as follows:

- It is best to incorporate passive solar design into a building during the initial design. The whole building approach evaluates it in the context of building envelope design (particularly for windows), day lighting, and heating and cooling systems.
- Window design, especially glazing choices, is a critical factor for determining the effectiveness of passive solar energy. Windows is like a knife has two side; one is useful and the other is harmful. When heat radiates through windows on hot hours it requires more cooling energy to maintain a comfortable temperature. Conversely, when heated air escapes from inside to outside during cooled hours, more heating energy is needed to reheat the space in order to maintain comfort.
- From economical point of view, double glazed L achieved minimum LCC in both Amman and Aqaba climate zones whereas double glazed H is the best choice for Berlin climate zone.
- Triple glazed window shows best performance than all other window types technically but it is not economically feasible in all climate zones.
- According to local conditions it is recommended to set room temperature in summer at 26 °C. which will give extra energy saving".

References

[1] B. Hunn (Ed.), Fundamentals of Building Energy Dynamics, MIT Press, 1996.
[2] J. Goulding, O. Lewis, T. Steemers (Eds.), Energy in Architecture: The European Passive Solar Handbook, Batsford for the Commission of the European Communities, 1992.
[3] G.F. Menzies, J.R. Wherrett, Windows in the workplace: examining issues of environmental sustainability and occupant comfort in the selection of multi-glazed windows, Energy and Buildings 37 (6) (2005) 623–630, ISSN 0378-7788.
[4] R. Sullivan, S. Selkowitz, in: Window Performance Analysis in a Single-family Residence, Lawrence Berkeley National Laboratory, University of California, USA, 1985, pp. 1–22.
[5] M.Z. Rousseau, in: Building Science Insight. Technical Report, Building Science Insight, 1988.
[6] K. Gertis, Sind neuere fassadenentwicklungen bauphysikalisch sinnvoll? teil 2: Glas-doppelfassaden, Bauphysik 21 (2) (1999) 5466.
[7] M.-L. Persson, A. Roos, M. Wall, Influence of window size on the energy balance of low energy houses, Energy and Buildings 38 (3) (2006) 181–188, ISSN 0378-7788. URL http://www.sciencedirect.com/science/article/B6V2V-4GR33TP-2/2/e6433e5%4c820f005a7ef8bffb06c60fb.
[8] J. Bokel (Ed.), The Effect of Window Position and Window Size of the Energy Demand for Heating, Cooling, and Electrical Lighting, 2007.
[9] U. Eicker, V. Fux, U. Bauer, L. Mei, D. Infield, Facades and summer performance of buildings, Energy and Buildings 40 (4) (2008) 600–611, ISSN 0378-7788.
[10] M.C. Singh, S.N. Garg, Energy rating of different glazings for indian climates, Energy 34 (11) (2009) 1986–1992, ISSN 0360-5442.
[11] K. Hassouneh, A. Alshboul, A. Al-Salaymeh, Influence of windows on the energy balance of apartment buildings in amman, Energy Conversion and Management 51 (8) (2010) 1583–1591, Global Conference on Renewables and Energy Efficiency for Desert, Regions (GCREEDER 2009), ISSN 0196-8904. URL http://www.sciencedirect.com/science/article/B6V2P-4Y965RY-1/2/4262554%337d23c5737568b4ff4d931ac.
[12] M. ArIcI, H. Karabay, Determination of optimum thickness of double-glazed windows for the climatic regions of turkey, Energy and Buildings 42 (10) (2010) 1773–1778, ISSN 0378-7788. URL http://www.sciencedirect.com/science/article/B6V2V-504BT17-6/2/600b97b%65debd5db93f1583f2f8863d9.
[13] Doppelintegral GmbH, in: INSEL Users Manual (2009), 8th ed., MS Windows, Stuttgart, Germany, 2009.
[14] ICC, in: International Building Code, International Code Council, 2009.
[15] MPWH, in: Energy Efficient Building Code, Ministry of Public Work and Housing, 2009.
[16] ASHRAE, in: ASHRAE Handbook of HVAC Systems and Equipment, American Society of Heating, Refrigerating and Air conditioning Engineers, 2008.
[17] ASHRAE, in: Ventilation and Acceptable Air Quality in Low-rise Residential Buildings Standard, American Society of Heating, Refrigerating and Air conditioning Engineers, 2004.
[18] M. Alsaad, M. Hammad, in: Heating and Air Conditioning, 3rd ed., University of Jordan, 1995.
[19] University of Wisconsin-Madison Solar Energy Laboratory, TRANSSOLAR Energietechnik GmbH, CSTB, and TESS, TRNSYS User's Manual, a TRaNsient SYstem Simulation program, 16 ed., 2006.
[20] MEMR, Ministry of Energy and Mineral Resources, 2010, www.memr.gov.jo.
[21] J. Arora, in: Introduction to Optimum Design, 2nd ed., Academic Press, 2004, May, ISBN 0120641550.